



Validation of SolarWorld Modules at the NREL Regional Test Center Site

Cooperative Research and Development Final Report

CRADA Number: CRD-15-595

NREL Technical Contact: Chris Deline

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5K00-77089
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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

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Cooperative Research and Development Final Report

Report Date: May 11, 2020

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: SolarWorld Americas, Inc. (ceased operations in 2019 due to acquisition by SunPower, Inc. in 2018)

CRADA Number: CRD-15-595

CRADA Title: Validation of SolarWorld Modules at the NREL Regional Test Center Site

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	\$120,000.00
Year 2, Modification #2	\$20,000.00
Year 3, Modification #3 & 4	\$24,000.00
TOTALS	\$164,000.00

Abstract of CRADA Work:

SolarWorld and the National Renewable Energy Laboratory (NREL) are entering into a cooperative research and development agreement (CRADA) in order to perform validation testing of SolarWorld’s Photovoltaic (PV) modules through the Department of Energy (DOE) Regional Test Center (RTC) program. This CRADA describes testing activities conducted specifically at the NREL-managed Colorado RTC site.

Summary of Research Results:

The Regional Test Centers conducted field trials to quantify the performance of SolarWorld’s silicon PV modules including monosilicon 290W 5 bus bar modules with glass-backsheet construction; high-efficiency PERC glass-glass modules at 280W; multicrystalline Si modules at 260W per panel, and bifacial PERC modules, glass-glass construction.

Four specific tasks were conducted, as described below: Design, Construction, Data Acquisition and Analysis, and Final Report. Through the process of the project, a custom PV installation was designed and installed for SolarWorld, and five reports issued including a final close-out report.

Based on the first 3 years of system performance (Nov 2016 - Dec 2019), the following characteristics stand out:

- Measured performance was within 3%-5% of modeled expectation for three module types (290W mono, 280W PERC and 280W bifacial PERC)
- The 260W monocrystalline string operated at 8% below expectation.
- Bifacial response of the bifacial PERC string was 3.4% above the monofacial PERC string, which is slightly below expectation based on measured rear-side irradiance (should be 4.4% bifacial gain).
- An extended outage in the NREL field was experienced from October-December 2018 mandated by the utility (Xcel energy) which may have influenced final results.

Task 1: Design

In this task, NREL worked with SolarWorld to develop a technical validation plan. This document went through multiple revisions starting March 2015 and was issued in a final version on 10 October 2015. This document was the controlling document for subsequent validation testing and was largely adhered to.

Initial project technical design was initiated April 2015 to establish technical scope and requirements for the partner. See Table 1 here and Figures 1 and 2 in Task 2.

Table 1. System summary information.

System parameter	System Spec
Array tilt angle	30°
Array azimuth:	180° (S)
Altitude (ft)	5790
Site Latitude	39.7403
Site Longitude	105.6217

Module Parameter	String 1	String 2	String 3	String 4
Manufacturer	SolarWorld	SolarWorld	SolarWorld	SolarWorld
Module Type	SW290 Mono	SW270 Duo	SW270 PERC	SW260 Poly
Technology	mono-Si	PERC bifacial	PERC	Poly-Si
No. of modules	8	6	8	8
String power (kW)	2.32 kW	1.62 kW	2.16 kW	2.08 kW
Date of Installation	11/3/2016	11/3/2016	11/3/2016	11/3/2016
Inverter	ABB PVI 6.0	ABB PVI 6.0	ABB PVI 6.0	ABB PVI 6.0
MPPT channel	Inv1 MPPT1	Inv1 MPPT2	Inv2 MPPT1	Inv2 MPPT2

Task 2: Construction

Modules were initially received from SolarWorld on June-July 2016. Field installation of PV racking and initial module mounting occurred in October 2016. Data acquisition for the system was initiated on 11/3/2016. System data was confirmed good without any initial start-up errors.

The SolarWorld RTC installation consists of four PV module strings : SW 290 Monofacial, SW 270 Duo (bifacial), SW 270 Mono PERC and SW 260 Poly. Each string consists of eight modules apiece, except for the SW 270 Duo string, which consists of six modules. Two PVI-6K grid-tied PV inverters connect to two strings apiece.

Figure 1 shows the SolarWorld installation at NREL, with a schematic view shown in Figure 2. All four module types were installed at the same time, with system turn-on occurring November 3, 2016.



Figure 1: View of the SolarWorld installation at NREL.

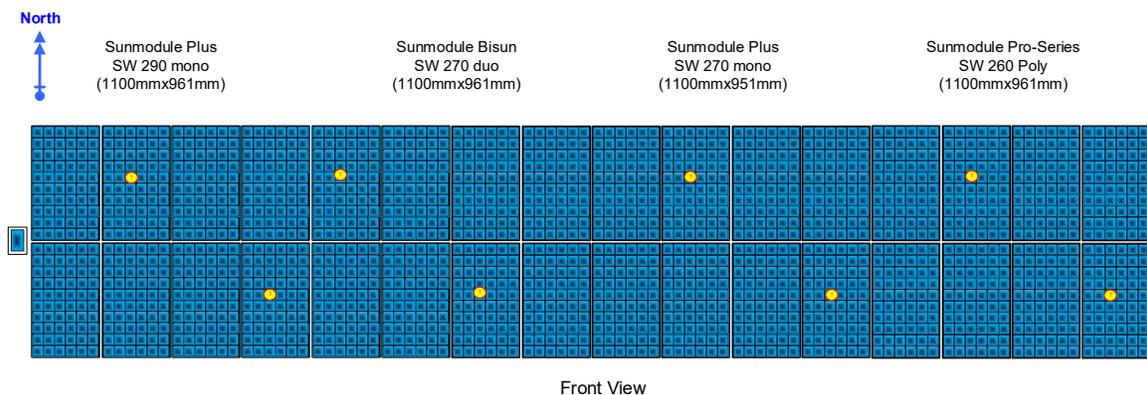


Figure 2: Module layout including mounting position of the forward-facing IMT reference cell, and module temperature measurements. A string with eight SW 290 Mono modules and a string with six SW 270 Duo modules are connected to the first PVI-6K string inverter. A string with eight SW 270 mono modules and a string with eight SW 260 Poly modules are connected to the second PVI-6K string inverter.

Task 3: Data Acquisition and Analysis

Field data was collected for the remainder of the project, and four test reports issued:

- 201705 NREL 6-month energy test report
- 201711 NREL 12 month energy test report
- 201808 NREL 18 month energy test report
- 201912 NREL final (36 month) energy test report

The raw performance data is considered Protected CRADA Information. Below are excerpts from a non-protected summary of the test procedure and some findings are presented below to describe data for the completed tasks.

Energy analysis: IEC 61724-3

1. Test Boundary

IEC 61724-3 is clear to require a definition of test boundary—i.e. which elements of the installation are inside or outside of the region of analysis. The inputs are typically defined by external weather conditions including global horizontal irradiance, wind speed and ambient temperature. The system outputs are usually defined to be AC energy delivered to the grid. In this case, because we are mainly interested in PV module relative performance, we can reduce model uncertainty by defining a system boundary closer to the PV strings. In this case, back-of-module temperature is measured, and plane-of-array irradiance is measured with a matched IMT reference cell. Output power is measured at the DC string level too. Monitoring equipment is detailed in Appendix A.

Other environmental conditions are uncontrolled—including ground albedo, natural snow/soiling and nearby shade obstructions. These factors will be described below. For the first three PV strings, proper data collection started November 3, 2016. This date is chosen for the start of the energy analysis.

2. Data analysis

Production data is averaged over 1-minute intervals, and filtered only for irradiance and DC power > 0. Prior to filtering, data availability was assessed to be 92% from two outages. Inverter 2 which was connected to PERC and Poly strings had an outage from 1/15/18 through 1/30/18. An additional 98-day forced outage was also logged between 10/4/2018 and 1/10/2019 due to an interconnect agreement dispute and re-negotiation with the site utility Xcel Energy. This was resolved by installing required production metering and updating research PV and Energy Storage assets at the NREL Regional Test Center campus site. This totals 2251 hours of lost data and system de-energized time (modules were at open circuit) to the experiment period under consideration.

This outage is removed from subsequent monthly and cumulative PR and model comparison. Monthly kWh production for each string is shown in Figure 3.

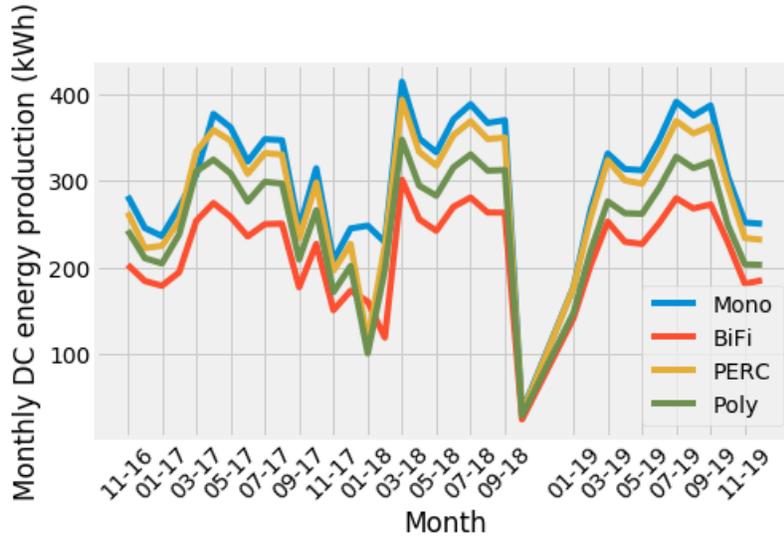


Figure 3: Monthly kWh production for the four SolarWorld strings. Note low performance in January 2018 for PERC and Poly strings due to a 2-week inverter outage.

Further Analysis of Bifacial modules

The main purpose of this test site is to evaluate the performance advantage of bifacial PV modules. We should first note that the field test site is not optimized for bifacial response. The ground below is relatively low—natural dirt and brush. Furthermore, although rear obstructions from back-mounted inverters were minimized, there is likely to be rear shading from racking and structural cross-members. This being said, we can assess the bifacial gain in energy for each month of our deployment according to:

$$BG_E = 100\% * \left(\frac{\sum P_{bifacial}/P_{mp}}{\sum P_{monofacial}/P_{mp}} \right) \quad (3)$$

$$Bifaciality \varphi = \frac{P_{mp, rear}}{P_{mp, front}} \quad (4)$$

Here P_{mp} is the measured single-sided power of each string from factory flash data, not nameplate rating, in order to more carefully account for the direct benefit of bifacial production.

On a cumulative basis, the SW 270 Duo bifacial module type produced 3.4% more energy than its monofacial peer (Figure 4). This was highest in the month of December, which experienced snow. In the context of the ability to capture available backside resource, this is about 1.2% less bifacial gain than expected, since the rear irradiance resource is on average only 7.6% of the front resource (Figure 5). This result is summarized in Table 5. The bifacial under-performance may be in part due to rack shading behind the bifacial modules, or non-uniform rear irradiance.

Table 2: Bifacial gain for SW270 Duo bifacial modules

	SW270 Duo Bifacial
Bifaciality ϕ (Eq. 4)	0.6
Grear / Gfront (Fig. 8)	7.4%
BGE (expected)	104.4 %
BGE (measured)	103.4 %

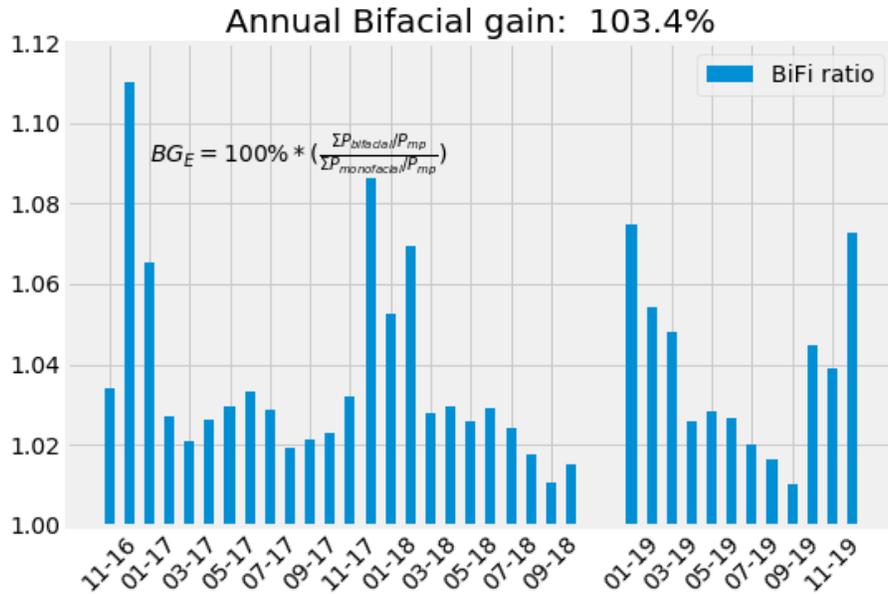


Figure 4: Bifacial energy gain for SolarWorld SW270 Duo bifacial modules deployed at the NREL RTC site.

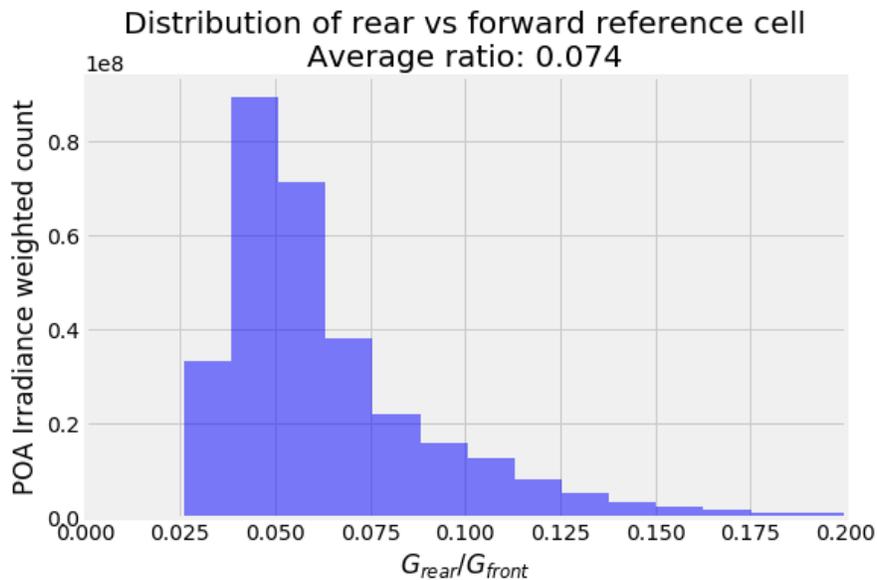


Figure 5: Distribution of G_{rear} / G_{front} weighted by POA irradiance as measured at the NREL site.

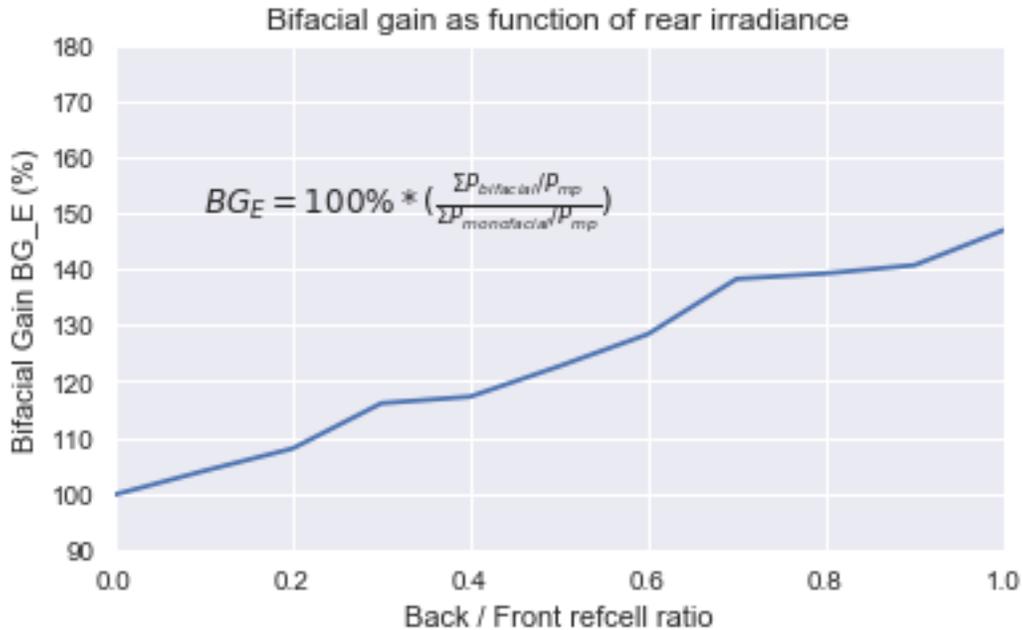


Figure 6: Bifacial gain as a function of rear-side irradiance.

Figure 6 also shows that the measured bifacial gain of these modules is relatively linear with respect to back-to-front irradiance ratio, therefore operation of these modules in a higher albedo environment is expected to increase bifacial energy production. According to Figure 8, for the majority of time available rear irradiance is around 0.074, consequently BG_E is correspondingly low on average.

Task 4: Final Report

The final CRADA report deliverable comprises this document.

CRADA benefit to DOE, Participant, and US Taxpayer:

Assists laboratory in achieving programmatic scope, adds new capability to the laboratory’s core competencies and enhances the laboratory’s core competencies.

Value to Partner and US Manufacturing:

The field test data collected provided valuable information and results that helped to establish performance capabilities of US-manufactured modules by SolarWorld Americas in 2016-2017. A serial defect in module connector leads identified in the field was also investigated at the NREL site, and helped to inform the manufacturer’s warranty / recall strategy. In Oct 2018, market forces led to the sale / acquisition of SolarWorld Americas to SunPower Inc. The intellectual property being investigated at this site was not transferred to industry during this acquisition, and the CRADA partner ceased responsiveness and wound down operations in January 2019, thus exiting this CRADA.

Subject Inventions Listing:

None

ROI #:

None

Responsible Technical Contact at Alliance/NREL:

Chris Deline | chris.deline@nrel.gov

Name and Email Address of POC at Company:

Eric Olson | Eric.Olson@SolarWorldUSA.com

DOE Program Office:

Office of Energy Efficiency and Renewable Energy (EERE), Solar Energy Technologies Office (SETO)